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World Mining

MARCH 1982

SPECIAL FOCUS: Slurry Pumping & Handling 46

World Mining

MARCH 1982
VOLUME 35, NO. 3

THE COVER

Tailings discharging at a Canadian potash mine are being observed. Economic, efficient pumping of slurry is an integral part of the mining world today, and this month's issue examines this subject in a five-feature *Special Focus. Photograph by Warman International, Inc.*

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SPECIAL FOCUS:

In this article, and the four that follow, WORLD MINING takes a close look at one of the most important operations in modern mineral processing

Slurry Pumping & Handling

By **Victor Cabrera**
Project Engineer,
Mountain States Mineral Enterprises
Tucson, Arizona, United States

The word slurry is now commonly used in bulk transportation. Specifically, "slurry" is defined as a mixture of solid particles in a liquid, usually water, from which the solids are easily separated. This is analogous to the passengers boarding a bus for a trip, and then parting from one another at the destination point.

The variety of bulk solids that are handled in slurry form covers a wide spectrum of mining product and waste material. Slurry handling is the key operation of most industrial mineral processing operations that move large quantities of bulk materials to process, distribute, and dispose the generated waste material. The list of materials is endless, including iron ore, copper ore, coal, limestone, phosphates, sand and gravel, bauxite, and tar sands.

Most mining and metallurgical processes of bulk raw material are designed to obtain valuable commodities, namely metal and non-metal minerals and energy material and impurities; the raw material is crushed, ground, and concentrated. Concentration processes such as flotation in metallurgical plants, pelletizing in the iron ore industry, and coal washing, all of which are in slurry form, made possible our access to copper, base metals, steel, and coal in the industrial quantities to which we are accustomed.

Slurry handling of solid water materials and tailings resulting from concentration processes is also widely used. This type of handling makes possible safe and efficient disposal of waste through neutralization of acidic contents while water in the slurry is recovered for re-use. Some of yesterday's tailings are today being treated again using slurry handling.

The Slurry Handling System

Proper understanding of the basis of slurry handling is necessary to successfully apply the technology. Basically, any slurry handling system is divided into two parts:

1. The slurry media of solid and water.

2. The slurry equipment or hardware.

There is close interdependence between the specific slurry and the equipment to handle it. Often, accommodations and trade-offs are made to fit one to the other. For example, slurry preparation is made to suit the equipment; conversely, the fine grinding of raw material that is required for metallurgical flotation, cement manufacturing, and gold liberation from its ores, makes efficient slurries. On the other hand, dredging operations involving rock and gravel require special equipment to keep large solids in suspension.

The Slurry Media

The purpose of slurry handling is the transportation of solids suspended in water via pipeline. Thus, it is desirable, from an economic standpoint, to obtain a slurry with the maximum solids concentration that is compatible with the equipment capabilities.

During slurry handling, the slurry media behaves like a fluid. The velocity of the slurry inside the pipeline is sufficient to keep the solid particles in suspension. The parameters affecting slurry hydraulic behavior inside the pipeline are the solids' particle size and specific gravity, and the solids concentration. These affect the tendency of solid particles to settle and the density of the slurry.

The parameters affecting the wear of pump and pipeline materials are the solid particle abrasiveness and the corrosive effect of the slurry media. Solid particles that are angular in shape with a high hardness index are more abrasive than other particles. The abrasiveness is increased in function of flow velocity, an effect analogous to a river eroding its banks more rapidly at flood.

The corrosiveness of the slurry media is chemical in nature. Dissolved oxygen and residual acids tend to attack metal surfaces, especially at the intra-granular metallic boundaries. Oily compounds from flotation and ion exchange processes destroy natural rubber. Some synthetic elastomers, such as neoprene, used as rubber substitutes, are impervious to attack from petroleum oils and some chemical action. On the other hand, the slurry media can be treated for chemical neutralization and oxygen removal with special additives if they do not affect the process. This treatment is beneficial to the pumping equipment and the pipe material downstream in the slurry flow.

The slurry equipment: Process plants and long distance slurry pipelines handle slurry with pumps, valves, pipeline, and control instrumentation. As any steady state continuous operation, slurry handling can be partially or totally automated with remote controlled instruments, telecommunications, and computer control. These controls keep the slurry system in balance.

The most common pump for slurry handling today is the centrifugal type, which is capable of handling up to 20,000 gallons per minute with 200 feet of head per pump stage. High pressure applications are performed by reciprocating pumps. Other types of special pumps, such as diaphragm and Moyno, are more restricted in their use.

Slurry pumps are divided according to their mechanical features as follows:

- Centrifugal type: horizontal, vertical, and submersible
- Reciprocating type: plunger and piston
- Special design: diaphragm, lock hopper, rotary ball, Mars pump, Moyno progressing cavity pump, hose pump, cylinder diaphragm.

Photograph by Warman International, Inc.

TAILINGS discharge at the end of a 3,650-foot pipeline at a Canadian potash mine. Solids deposit is 3,000 feet long, 1,000 feet wide, 150 feet high. Runoff goes into a settling pond.

Centrifugal pumps

Centrifugal pumps are an adaptation of ordinary water pumps with the necessary improvements for slurry handling. Design of slurry pumps includes the selection of materials constructed to resist abrasion, corrosion, and the extra load of heavier-than-water slurry. Since wear is a funtion of velocity, the pump must operate at a low rotational speed and the impeller has to be truly a radial flow design. Radial flow attained at low revolutions per minute, compared with axial flow, minimizes abrasion wear.

Centrifugal pumps are identified by their specific speed (Ns), which relates to flow (Q) (gallons per minute), head (H) (feet), and shaft revolutions per minute (n) as follows:

$$Ns = nQ^{½}/H^{¾}$$

For slurry service, the specific speeds of centrifugal pumps with radial vane impellers vary from 600 to 1,800 revolutions per minute.

Abrasion wear: There are three main types of abrasion wear:

- Gouging abrasion when coarse, angular particles tear fragments of the wearing surface. Examples are gravel dredging and primary cyclone feed.
- Grinding wear of fine particles crushing between two surfaces in close proximity. For example, the side clearance between the impeller and the stuffing box.
- Erosion abrasion caused by the impingement of impact of solid particles on the wearing surface. Examples: the cutting wear and deformation wear that are respectively parallel and normal to the flow direction.

Abrasion resistant meaterials: Tough materials are used for gouging abrasion. Cast iron, often with 3 percent nickel, is the basic pump material employed when protection against mild corrosion is needed. Ductile-iron and cast steel offer extra strength in high pressure applications or when the pump is exposed to high impact shock. Austenitic manganese steels are tough, free of residual stresses in castings, and they also work-harden with use, so they are preferred in dredge and gravel pumps.

The use of composite materials is prevalent for grinding and erosion abrasion without unduly high impact shocks. Metal liners made of Ni-Hard and heat-treated high-chromium iron with Rockwell C hardness numbers between 55 through 63 are excellent for these two types of abrasion.

Natural rubber is the most common non-metallic liner used for abrasive service, provided the liquid phase of slurry contains no hydrocarbon, which destroys the rubber. Man-made elastomers such as butyl rubber, neoprene, nitrile, hypalon, and polyurethane are also used. Resistance to erosion abrasion is enhanced by elastomers with high resilience characteristics, low hardness, and high tear and cut resistance.

Ceramics are applied less frequently as liner material because of their low resistance to thermal and impact shocks. An exception is the solid silicon carbide refrax type ceramic for selected fine solid particle slurry applications.

Materials resistant to chemical corrosion are rubber, man-made elastomers, ceramics, and steel alloys of nickel, chromium, and molybdenum. Corrosion attack of the metallic intergranular boundaries induces stresses affecting the life span of the pump. For this reason the metallic liners should be evaluated for the particular applications to offset the possibility of the development of corrosion cracks in the pump.

Pump wearing areas: The areas of the pump most prone to wear, in order of severity, are as follows:

- Suction side wear plate liner. The replaceable liner is periodically rotated to equalize wear. A replaceable wear plate is also provided on the gland side adjacent to the impeller.
- Impeller, particularly at the eye vane inlets, suction side impeller shroud, and the vane tips. The closed impeller design is preferred to the open impeller because it is more robust and efficient. The three or four vanes in the impeller are extra thick on the parts subject to most wear.
- The casing and side walls adjacent to the impeller tips. Replaceble liners protect the casing from wear. In the case of metal liners, the mating faces are accurately ground to match the casing surface and permit a close fit joint when the casing is bolted together.

All elastomer liners are pressure molded, easy to remove and provided with bolts to secure the liners firmly in place. For some severe abrasion applications, the pump casing is relined by trowelling epoxy "Nordbak" paste with embedded "Coors" ceramic beads. The ceramic beads held in the cured "Nordbak" epoxy matrix form an effective anti-abrasive surface.

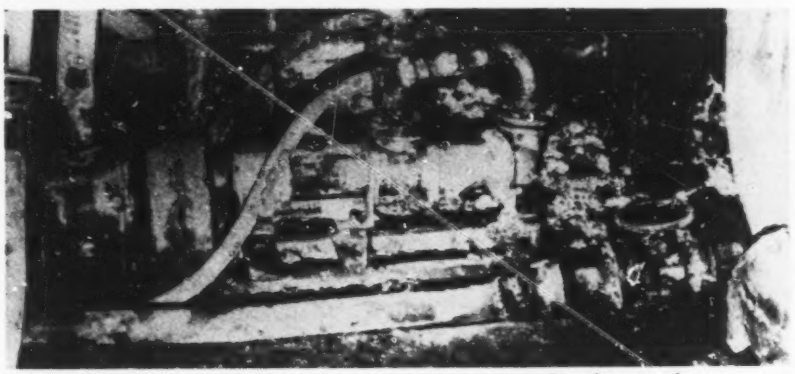
- The stuffing box packing and sleeve. Unless precautions are taken to prevent the entrance of solids into the stuffing box, rapid wear will result in the shaft sleeve. Current pump designs include hydrodynamic vanes on the impeller facing the stuffing box seal. These vanes minimize the pressure at the seal and its contamination with slurry material.

Stuffing box mechanical seals are in common use. Some pump manufacturers favor the centrifugal type and the packed gland seal. This arrangement combines the hydrodynamic sealing vanes with packed box arrangement of graphite asbestos or teflon filled asbestos split rings. However, double seals with a clean barrier liquid, gland water, have proved highly successful. In these cases, water at higher pressure than inside the pump is injected through the lantern ring of the stuffing box. One disadvantage of the method is the dilution of the slurry with gland water, which by design can be minimized.

Bearings for slurry pumping are designed for heavy duty service, with a calculated life of 50,000 hours, which is higher than for water pumps. Oil lubricaton is preferred over grease. Sealed bearings are easily interchanged at short notice.

It has been pointed out that low revolution per minute operation is of the utmost importance to wear reduction. Therefore, electric motors or Diesel engines use V-belt drives and gear reducers to attain the required speed. V-belt drives are popular because pump speed is adjusted by changing the pitch diameter of the V-belt sheaves.

Although gear reducers are used on pumps with motors having 300 horsepower and above, V-belt drives are satisfactory for large motors and engines in the range of 1,500 to 3,000 horsepower. Motors and engines for slurry service must be rated with an adequate margin, say 20 to 40 percent, to cover upset conditions that may occur during start-up and emergency shut downs. Pumps driven by gear reducers often have variable speed couplings for slurry flow control, a feature that can also be adopted to V-belt drives.



SCREW PUMP from Netzsch-Mohnopumpen is shown at work underground.

Reciprocating pumps

The mud pumps used in the oil drilling industry were developed to generate high pressures and to resist the attritional effects of abrasive laden slurry. Based on this experience, the reciprocating slurry pumps, larger in size and capacity, are standard equipment in long distance slurry pipelines.

Reciprocating slurry pumps are more efficient than centrifugal pumps because of the positive displacement feature. They are also more costly because of their close tolerance fabrication and higher weight compared with centrifugal pumps. Pistons and plungers in the reciprocating pumps induce pressure on the incoming slurry admitted to the pumping chamber. This chamber has valves to admit the low pressure slurry and discharge the high pressure slurry.

Piston reciprocating pumps, which are double acting, are applicable to slurries that are not very abrasive and for pressures up to 2,000 pounds per square inch. These high volume pumps are used for coal, phosphate sized to 8 mesh, and limestone sized to 28 mesh.

The plunger reciprocating pump is single acting and it therefore delivers less volume than the piston type. The pump is adequate for abrasive and fine particle slurries such as hematite, magnetite, and copper concentrates with pressures up to 3,000 pounds per square inch. The small velocities of slurry flow tolerated in the reciprocating pumps reduces their capacity considerably. For this reason the pumps are multiplexed (parallel multi-unit mounting). In addition, several multiplexed pumps are needed to attain the capacity necessary for a given application. For example, if up to five triplex pumps installed in parallel are needed for a certain pumping station, one of the triplex pumps is always on standby for continuity of operations during the repair or maintenance of any other pump in the pumping station.

Reciprocating slurry pumps are designed so that the parts subject to the deteriorating effects of slurries can be easily and quickly replaced. The parts more subject to wear are the pump valves and valve seats because of slurry movement and constant metal to metal pressure during the closing of the valves. In the piston pump, the piston that displaces the slurry runs in a renewable metal cylinder or liner. The piston rod runs through its packing and presents a second area of sealing and wear. On the other hand, the plunger pump with its packing is the only area subject to wear.

It has been established that slurry velocity should not exceed 12 feet per second through the valve, to minimize erosion effects. This dictates the amount of bearing area that can be used. Several materials have been employed to extend the life of valves and valve seats, including steel alloys and polyurethane. Sever-

al configurations have also been tested to provide good seat at valve closing and the appropriate distribution of the valve closing load. Valve life varies from as low as 100 hours to 1,000 in abrasive slurries; in less abrasive slurries, such as coal, the valve life approaches 1,200 to 1,800 hours.

The purpose of packing is to close the clearance gap between the piston rod or plunger and the stuffing box parts. It effectively prevents slurry flow outside of the pumping chamber while permitting the reciprocating movement of the piston rod or plunger. Hard packing, which is to be lubricated for high pressure service often reaching above 2,000 pounds per square inch, is preferred over soft packing.

The introduction of water flushing into the stuffing box prevents slurry migration outside the pumping chamber and into the packing when the plunger is on the suction stroke, and it is entering the packing. A positive displacement pump is used for flushing because it is desirable to supply water at a constant metered rate. The flushing water is introduced by a special lantern ring to the bottom of the plunger. About 4 gallons per minute of flushing is required per plunger.

The drives for reciprocating pumps are usually large electric motors, Diesel engines, and turbine engines. The driving train thus contains gear speed reducers and variable speed couplings and controls. One limitation on driving revolutions per minute is the need to maintain the slurry velocity at a rate below 12 feet per second at the inlet check and outlet check valves. Also, it is usual to have one standby unit ready to go on line to replace another unit for repairs or maintenance.

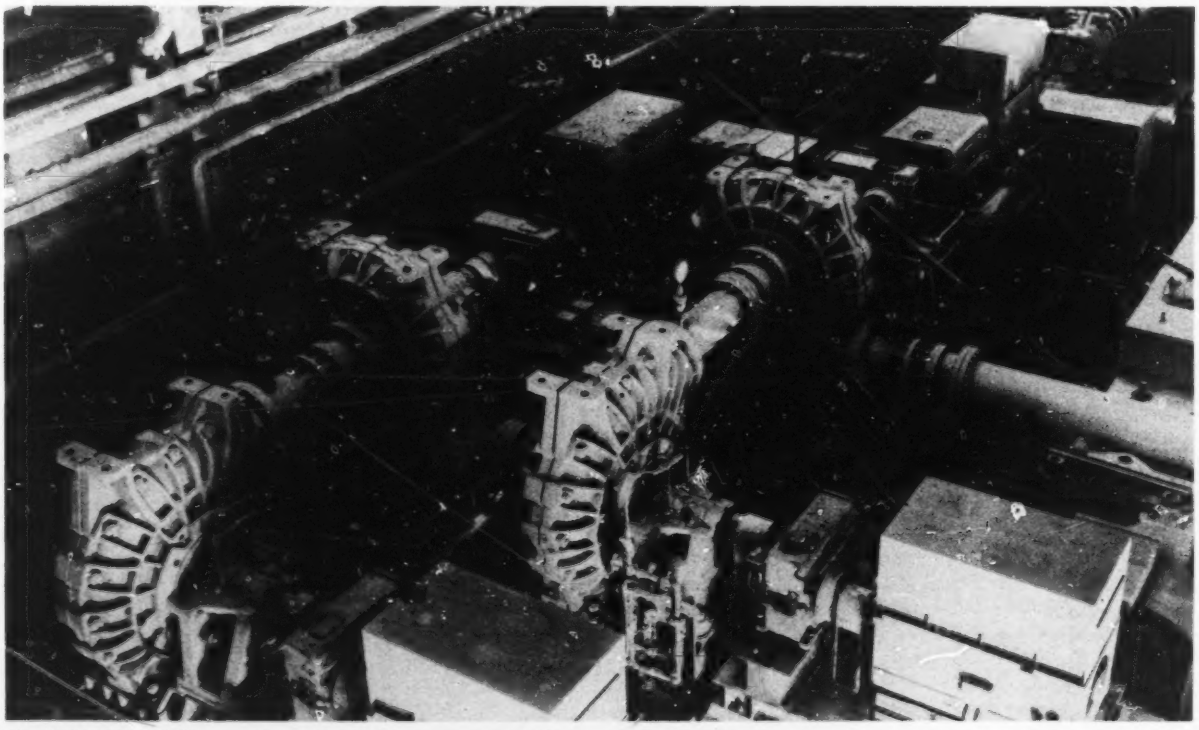
Non-contact pumps

Non-contact slurry pumps, which are different from centrifugal and reciprocating pumps, are gaining acceptance today. In the non-contact pumps, the abrasive slurry is isolated from the pumping parts subject to wear with a liquid or elastomer interface. The main advantage of non-contact pumps over other pumps is their long life between maintenance periods. Another advantage is that non-contact pumps' pumping equipment can be located away from the pressure vessels in contact with the slurry.

Liquid interface pumps: The Mars pump and the lock-hopper pump use oil and water, respectively, to interface slurry during pumping operations. Mitsubishi's Mars pump is a duplex double acting piston pump using an oil barrier that prevents contact between the slurry and the pistons and cylinders. The lock-hopper pump has its water and slurry phases separated with free moving rubber balls in the pressure vessel used for pumping. The Mars pump is used successfuly to hoist deep gold ore slurry in South African mines. The lock-hopper pump is a safe and efficient coal transporter, used in English underground collieries to transport coal from underground to the surface.

Elastomer interface pump: The ubiquitous diaphragm pump is a good example of a long lasting pump. It has an elastomer body with an inlet check valve to admit slurry and a discharge valve. Diaphragm valves are basically for low pressure applications (below 100 pounds per square inch). Examples include the Warren Rupp Company's SandPiper air powered double diaphragm pump and the Dorr OGS pump.

The high pressure hydraulic exchange pump (Zimpro Inc.) is a well-tested non-contact slurry pump for high pressure, up to 3,000 pounds per square inch applications. The basic operation consists of positive feeding of low pressure slurry to a bag-shaped diaphragm, which is located inside a pressure vessel filled with oil. Hydraulic pressure applied to the oil forces the slurry out of the diaphragm at high pressures. Pumping proceeds in a continuous manner,



TACONITE TAILINGS pump house. Each of the pumps weighs in excess of 40,000 pounds. Tailings are pumped 23,000 feet at a rate of some 15,000 gallons per minute.

ceeds in a continuous manner, using two pressure vessels alternately with inlet check and outlet check valves.

Screw pumps

Screw pumps are in a class by themselves. They are highly versatile for difficult-to-handle slurries that are viscous, abrasive, and contain some large particles. The rotating screw generates progressing cavities, which deliver uniform and continuous flow with pressures up to 1,000 pounds per square inch and self-priming suctions up to 28 feet. Examples are the Moyno and the Pumpenfabrik Wangen GmbH pump.

Instrumentation and valves

Instruments and valves for slurry handling are basically the obstruction-less type. Instruments mounted outside the slurry pipe by indirect methods measure slurry flow velocity, density, and pressure. Contact type instruments measuring pH and temperature are secondary in importance to the three parameters just mentioned.

Instruments: Magnetic flowmeters and ultrasonic Doppler effect instruments measure flow velocity. Nuclear gauges and ultrasonic sound absorption instruments measure the slurry density. These are calibrated against known standards and relay measuring inputs with transducers. These transducers convert the magnetic, ultrasonic, and pressure inputs into electrical signals for reading and control.

Once the operating parameters of flow velocity, slurry density, and pumping pressure are defined for steady state conditions, the desired control can be established. These controls are either manual or automatic. However, manual overrides are still necessary in automated systems in order to fine tune the operation of the slurry system during start-up or emergency conditions. Operators will develop confidence as they find that slurry systems are rather stable within a narrow band of designed flow velocities, slurry densities, and pressures before developing upset flow condition. The proper identification of those limits with alerting red lights or bells enable the operators to institute prompt remedial actions.

Instrument readouts at key points in the slurry pipeline; namely, pump feed, pump discharge, pipeline intermediate points, and discharge, are normally redundant, to prevent breaks of data gathering due to temporary failure of a given instrument. The additional cost of providing redundancy is amply compensated by the benefits of effective monitoring of the slurry system.

Valves: Valves for slurry application are the full-flow type because flow obstruction can cause deposition of the solid phase and eventually induce plugging of the pipeline. Full-flow plug valves are used in full open and full close positions only. Special attention is given to valve operation for flow diversion; the valve closing the flow, and the valve opening to divert this flow are interlocked so that flow velocity and continuity are minimally affected. This valve interlocking is usually done by instrument control, and solenoid actuators of the fail-safe type, and motor operated valves.

Throttling valves are occasionally used for flow branching and energy dissipation. These valves are designed for smooth flow under velocity change that often create a Venturi effect. Ceramic annular chokes restricting flow by increasing friction are used to dissipate extra head in the slurry system. Throttling valves constricting flow are of two kinds: the diaphragm valve with an annular constriction, the butterfly valve with a smooth face and shape, and the flexible hose pinch valve, in which flow is throttled by constricting the hose. These throttling valves are lined with abrasion-resistant elastomers, metal alloys, and ceramic.

- Flow velocity instruments:
Magnetic flowmeter, Ohmart
Ultrasonic flowmeter, Polysonic
- Pressure:
Diaphragm sensing, Tescom
- Throttle valves:
Pinch valve C, Clarkson
Eccentric butterfly, Duriron
Flexible hose pinch valves, Larox
- Density meter:
Nuclear gauge, Ohmart
Ultrasonic absorption, Envirotech
- Plug valves:
Full flow, DeZurik
- Computer instrumentation
Digital, Foxboro, ITT, 3M

Pipe material

Slurry pipelines can operate without pumps but not without the pipeline. In fact, there are many gravity-type slurry pipelines handling mineral tailings and concentrates where the main equipment is just the pipe material. This fact underscores the importance of pipe material selection and design, as these two factors affect the longevity and efficient functioning of the slurry handling system.

Steel: Carbon steel pipe is most readily used because of its economy, versatility, and ease of construction. Several grades of carbon steel are available from the ASTMA-53 steel, which has yield strength of 30,000 pounds per square inch, up to the API-SLX-60, the

How to receive more information

To receive more information on any of the slurry pumping and handling hardware described in this article, use the reader service card on page 17, and circle the numbers of any of the categories listed below. Your inquiry will be forwarded to manufacturers of the types of equipment for the category indicated.

Slurry pumps
Pumps with metal and/or rubber liners.... Circle No. 200
Metal dredge pumps ..... Circle No. 201
Pumps with recessed impellers ..... Circle No. 202
Submersible slurry pumps..... Circle No. 203
Screw centrifugal pumps..... Circle No. 204
Piston and plunger pumps..... Circle No. 205
Elastomer interface pumps ..... Circle No. 206
Screw pumps..... Circle No. 207
Pump drives ..... Circle No. 208

Slurry handling materials
Rubber lining material..... Circle No. 209
Plastic pipe ..... Circle No. 210
Rubber hose..... Circle No. 211
Steel pipe ..... Circle No. 212

Slurry valves and instrumentation
Slurry throttle valves..... Circle No. 213
Slurry plug valves..... Circle No. 214
Flow velocity instrumentation..... Circle No. 215
Pressure sensing instrumentation ..... Circle No. 216
Density meters..... Circle No. 217
Computer instrumentation and supervisory control
..... Circle No. 218

strength of which doubles this figure.

Special low alloy carbon steels containing manganese and nickel have yield strengths up to 100,000 pounds per square inch; for example, Transcl from Jones and Laughling Steel. This pipe and the hardened wall pipe, 500 Brinell hardness number, are designed for improved abrasion and corrosion resistance. However, these materials are more costly and less standardized than carbon steel.

Plastic and composite material: The next most popular pipe material is the assortment of plastics including PVC, polyethylene, polypropylene, and the extra strength high density and ultra high molecular weight polyethylene. Plastic pipes are lightweight, versatile for a variety of slurry applications and rather easy to install. Plastic pipe, like steel, is easy to string weld or join by a variety of couplings. A major advantage of plastic pipes is their resistance to corrosion, and if properly selected, resistance to abrasion. On the other hand, plastic pipes are restricted to internal pressures below 200 pounds per square inch while steel pipe has no pressure limitations to speak of. This is a reason why composite steel body pipes with liners of elastomers, plastic, and expoxy are in vogue today.

Asbestos cement: The asbestos cement material (Johns Manville Transite) is commonly applied especially in gravity ore tailings pipelines. This pipe is widely available and it is resistant to abrasive slurries requiring a minimum of maintenance once it is installed overland or buried. It is applicable for low pressures not exceeding 200 pounds per square inch. Composite steel and cement asbestos pipe has the advantage of high strength, resistance to abrasion, and string welding features for efficient field construction.

Elastomers: Natural rubber and elastomers are used for low pressure and short distance slurry pipelines, such as in process plants. They resist abrasion and corrosion extremely well. For this reason, composite pipe of carbon steel body and rubber-lined pipe material are used for abrasive slurries.

Specialty materials: Chemically corrosive applications require costly specialty pipe materials, including stainless steels 304 s.s.and 316 s.s. and proprietary materials such as Monel, Inconel (International Nickel), and Hastealloy (Union Carbide) that are nickel, manganese, chromium, and vanadium steel alloys. These materials as well as other metals including aluminum, titanium, and zirconium, are suitable for low abrasion slurries at relatively low flow speeds.

Another specialty material, fiberglass reinforced polyester (FRP), is resistant to corrosion but it is seldom suitable for slurry application because the pipe is not resistant to abrasion.

Table 1.
OGJ Morgan pipeline cost index

Cost Component	1977 Index	1981 Index	Escalation
Steel line pipe	139	199	43 percent
Pipeline construction	128	177	27 percent
Pipe coating	124	166	34 percent
Pump equipment	144	201	40 percent
Electric motors	159	239	33 percent
Steel storage tanks	140	193	38 percent
Radio & microwave equipment	115	145	26 percent

Pipe protection

Protection of pipe material for slurry handling is both internal and external. Internal protection includes measures to minimize abrasion and corrosion wear and structural protection against underpressure and overpressure caused by upset conditions. External protection is necessary to shield the pipe from such things as hostile environmental temperature changes, ultraviolet sunlight radiation, electrochemical attack of moisture-laden earth, and for security reasons.

Internal abrasion-corrosion: Carbon steel pipe has allowance in wall thickness for abrasion-corrosion wear. This wear is minimized by using low flow velocities, say below 10 feet per second, and by the corrosion inhibitors that are added to control pH and to remove oxygen in the liquid phase of the slurry. Popular additives are lime, soda phosphate compounds, and calgonite.

Although about twice as expensive as carbon steel, composite material pipe using highly resistant to abrasion-corrosion plastic, epoxy, and rubber liners, is very successful for trouble-free, high-pressure slurry handling.

The high molecular weight polyethylene pipe, such as Phillips' Drisco, is recommended for low pressure application, such as in-plant and gravity lines, because of its abrasion-corrosion resistance, its economy of installation and its wide availability. The same can be said of the asbestos-cement pipe, which is also economical.

Interal vacuum and overpressure: Underpressure or vacuum in the pipe can cause its collapsing. Adequate protection is made with pipe vents located at high points along the pipeline route, which admit air to compensate for vacuum created by slugs of slurry separated by differential overspeeding. Conversely, overpressure can rupture the pipe if the hoop strength of the pipe is exceeded. Overpressure, especially in reciprocating pumping installations, is prevented by locating rupture discs on the discharge secton of the pump. These discs break under a set load, functioning much like fuses in electrical systems. The rupture discs seal the top of special tanks, which are mounted on the pipe. These tanks function as pulsation dampeners. Pulsation must be controlled in reciprocating pumps in order to prevent damaging structural stresses to the pump body and pipe.

External protection of pipe material: Only metal pipe requires external protection such as paint for above ground pipe. When metal pipe is buried it is lined with anti-corrosion multi-layer coatings of tar or epoxy plus tar paper wrapping. The external coating is tested with high voltage spark (Holiday) to check the thoroughness of the protective cover. In addition, buried metal pipe requires cathodic protection to prevent electrolytic wear of the metal. Impressed electric current and/or zinc spend anodes prevent this type wear.

Plastic, asbestos cement, and rubber pipes are resistant to atmospheric agents and they do not require external protection when installed above or below ground. All are also unaffected by ultraviolet sunlight radiation, with the exception of some plastic materials such as PVC.

Cost considerations

Although recent materials and labor prices have tended to stabilize due to the current recession, pipeline capital and operating costs escalated during recent years at approximately seven percent per year. Using the 1977 prices given in the reference (Slurry Handling by V. Cabrera), a factor of 1.4 should be applied to update prices in 1982, as the compound interest, or inflation, of five years at seven percent is equal to 40 percent. This escalation is shown in more detail in Table 1.

Reference

Pipeline Economic Report, Oil & Gas Journal, November 23, 1981. ■